LCA Methodology

Component Manufacturing Analysis

A Simplified and Rigorous LCI Method for the Manufacturing Stage

Yasuhumi Mori[1], Gjalt Huppes[2], Helias A. Udo de Haes[2] and Suehiro Otoma[1]

[1]National Institute for Environmental Studies, 16-2 Onogawa Tsukuba, 305-0053, Japan
[2]Centre of Environmental Science, Leiden University, Einsteinweg 2, NL-2300 RA Leiden, The Netherlands

Corresponding author: Yasuhumi Mori; e-mail: mori-y@nies.go.jp

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Abstract. To date, numerous simplified Life Cycle Assessment methods and techniques have been developed to reduce complexities associated with practical application. However, these methods often identify critical elements according to subjective considerations. In this paper, we develop and apply a new type of Life Cycle Inventory method – Component Manufacturing Analysis (CMA) – that is easy to implement and less arbitrary. Application of CMA requires identification of all product components and their associated weights, which are then entered into a factory-type database. Because the factory database has a rigorous yet generic structure and because calculation is done automatically, the application of CMA tends to be less arbitrary and more complete than other simplified methods. Results of a case study on beverage vending machines show that the manufacturing stage is a significant phase in the whole life-cycle inventory of a product. We conclude that CMA shows promise for further development and future application.

Keywords: Case study, vending machine; CMA; component; factory-type database; LCA; LCI; Life Cycle Assessment (LCA); Life Cycle Inventory (LCI); manufacturing; simplified LCA

Introduction

New approaches for simplification needed

Life Cycle Assessment (LCA) is a valuable tool for environmental management (De Smet et al. 1996), and can offer systematic and comprehensive environmental assessment of goods and services. Detailed LCA, also called full LCA, has been considered as the 'real' LCA. Many efforts to develop full LCA have been made, as follows (Udo de Haes 1993):

- Standardization of methodology (Heijungs et al. 1992, Lindfors et al. 1995, SETAC, ISO)
- Building up of databases (BUWAL, ETH, APME, etc.)
- Development of software (survey by Siegenthaler et al. 1995)

These efforts have not been entirely successful because LCA has many complexities in both methodology and practical applications. Therefore, a number of simplified LCA methods that take less time and labor have been proposed. Screening, a procedure that identifies which elements of LCA can be omitted and where generic data can be applied (Christiansen et al. 1997), has been considered to be a practical technique for simplifying LCA. Screening involves treating only hot spots, selecting key issues and excluding processes that are included in every alternative. A technique called iterative screening was proposed to help the screening procedure (Fleischer et al. 1997).

Difficulties in screening are related to the fact that an identification of critical elements is somewhat subjective, leaving room for arbitrary and even manipulative omissions. Results for a screening LCA for a certain product will depend on other products included in the study and on the type of analysis performed.

Thus, there still remains the requirement for an easy, common, simplified method with less arbitrariness that will provide an identical outcome for the same product in every case. Such a method would facilitate the evaluation of LCA scores for a wider range of products. It would stimulate competition among the products in a market, and may thus contribute to a progressive reduction of environmental burdens. This article proposes a new approach to such an easy and reproducible life cycle inventory (LCI) method for the manufacturing stage, as a step towards a simple, broadly applicable, standardized LCA method. Although this approach concentrates on the manufacturing stage, after cooperating with LCI methods for other life stages, this approach will contribute to provide sufficient LCI results for the whole life stages.

1 What is CMA?

1.1 Main characteristics

Component Manufacturing Analysis (CMA) has two central elements. One is that products are composed of components which are produced in the manufacturing process. Thus, a product is composed of manufacturing outputs such as iron boxes, plastic parts and motors. In CMA, a product is regarded as an integration of such intermediate manufacturing outputs. These manufacturing outputs are measured in terms of mass only. Other aspects of manufacturing such as cutting length are left out of consideration in CMA. For other types of products such as a chemical product which consists of ingredients or is made from reactants in a chemical reaction, the ingredients and the reactants, instead of components, can be utilized as intermediate manufacturing outputs.

The other CMA element is a database, set up for each factory type. Each manufacturing output comes from a factory. A factory must have some relation to environmental burdens. Factories can be categorized according to the similarity of their transformation characteristics, like forming, connecting or small part production. A product can be related to the types of factories that made the manufacturing outputs – i.e. the components – instead of the real processes which in practice cannot all be known. Thus, in CMA we can develop Life Cycle Inventories using a factory-type database.

CMA differs from a process-tree approach. In CMA, manufacturing is represented as the flow of components through certain factory types; information related to manufacturing can be obtained directly from a product and factory-type database. In this approach, it is not necessary to establish full process trees to analyze the actual manufacturing stages. Additionally, this approach does not need a process database like existing LCA software (Pre Consultants 1997), because the factory type represents an aggregation of more than one process which are all performed in the categorized factories. Although if real processes all were known and the database for the processes were perfect, it could be possible to make the data for factory-type through the process database, in practice the factory-type database can be filled through the data measured from the whole factory.

1.2 Life cycle stages

The life cycle stages analyzed by CMA include component production, product assembly and transportation, and within manufacturing, and also between manufacturing and the other three stages. However, CMA does not cover material production, utilization and waste management (Fig. 1). The reasons are the following. For material production, there already exist some usable databases such as BUWAL, ETH and APME that can help LCI in this area. For the utilization stage, data related to environmental burdens such as energy consumption can often be collected by actual measurement or from information such as catalogs published by a producer, and mostly is very product specific. Databases for the waste management stage are under development. However, for the manufacturing stage, especially for a complex product, there are neither simple applicable methodologies nor readily usable databases.

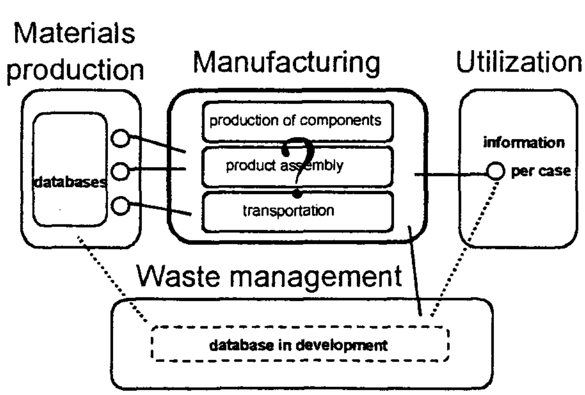

Fig. 1: Why focus on manufacturing?

1.3 How to apply

The first task in CMA is to break down the product into its components. The kinds of components to be included in the product should be specified. The second task is to measure the weight of each component. For the ingredients and the reactants, some information should be used, such as an ingredient list and a reaction formula, instead of breaking down and measuring the weight. The third is to link these data to the factory-type database. Factory types in which the components are produced are identified. The factory types have relationship coefficients between input and output, as well as environmental burdens per unit output (in kg). The relationship between input and output yields the necessary data on resource needs from the material production stage. Multiplying the component weights by the coefficients yields the value necessary for the inventory and the necessary data on resource needs. The data on the resource needs are sometimes mass values of materials and sometimes components used in the manufacturing. The latter type of information on the resource needs is treated to calculate the value for the (CMA based) manufacturing part of the inventory again. For the materials, the database of material production can be applied, although the analysis of the material production is not the scope of this research. This is generally a stepwise procedure if the components are complex in themselves. Whole-product weight is used for the coefficients in the case of a factory in which a final product is assembled.

Factory types are defined partly using a top-down approach, based on an existing sectoral classification of industries. A bottom-up approach is also used to structure factory types on the basis of representative processes for basic transformations in manufacturing, like forming and connecting (Fig. 2). Some existing sectoral classifications may already correspond to some factory types. Classifications that have similar processes are combined into one factory type even if these processes belong to completely different sectors from current classification. Vacuum cleaner assembly, for instance, might have the same environmental burden coefficients as those of washing machine assembly and even those of car assembly. On the other hand, some of the current sectoral classes must be divided into different factory types that have different representative processes. Thus, factories of a certain factory type produce a similar type of product or a similar set of products if the product has co-products. In the latter case, an allocation rule is selected and applied before determining the coefficients for the inventory and the necessary data on resource needs.

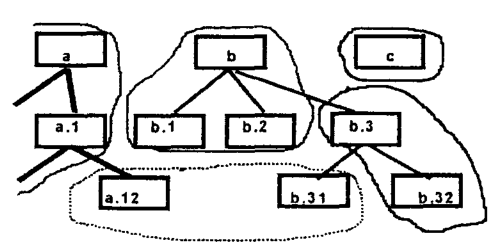

Fig. 2: Restructuring of sectoral classification

1.4 Filling of the database

There are two types of data that can be put into the factory type database. One is original data from manufacturers on the basis of a limited number of related case studies. Some products, especially complex products, need many kinds of factories in the manufacturing stage. These factories can be correspondingly categorized into many factory types. If products for case studies are chosen carefully, the necessary data for all factory types can be gathered. The data from these manufacturers can be put in the database after some manipulation, such as taking averages.

The other data type is that reported by manufacturers to organizations such as national governments. Some enterprises are obliged to submit emission data such as drainage water quality and exhaust gas concentrations. Comparing and sorting these data could help to establish the factory types and fill the database. One difficulty in using reported data is confidentiality. Permission might be necessary to make the data available to the public. Taking an average might help in obtaining such permission. Another difficulty is that emission data do not usually include input data such as consumption of water, materials and other resources, or production records. If this is the case, it will be necessary to supply these data from other data sources and to link the emission data with them.

As an option, differentiation between countries is possible, in principle. Input-output data on environmental aspects in one country might be different from those in other countries. The components can be linked to the concerned factory type after specifying the country where the component was produced.

A main advantage of the CMA approach is that information produced for one specific case study can be re-used in many more applications, by using them in the framework of the factory types.

2 Application

2.1 A case-study product

We performed a case study on beverage vending machines, which are considered to be a type of complex appliance, in order to examine the applicability of the CMA method. The vending machine evaluated in this research was one of the types in most widespread use in Japan in 1995. For the time being, no real factory type data are available, nor is there a specified full set of factory types. Being a quite complex product, we think it is a very useful first step in setting up the CMA system.

The functional unit of the product system concerns the dispensation of canned beverages over an average lifetime of 7.5 years. For the transport phase, we assumed a distance of 100 km for the distribution of the materials, and 100 km for the distribution of the vending machine.

For estimating the share of manufacturing in the total life cycle, we also included the other life cycle stages. Energy consumed during vending machine use is electricity only, and it is possible to generally infer the total energy consumed from the machine's lifetime and the specifications of parts such as the compressor unit. Average power consumption and the compressor's operating rate are observed values.

The scenario for the disposal phase is that the vending machine was dumped in landfill near the shop where the product was used. Waste generated at the material production and manufacturing stage was also dumped in landfill near the facilities. Although recyclable waste was included in the waste of the manufacturing stage, it was assumed not to be recycled and dumped, because data for waste management were lacking.

2.2 CMA application

Step (a): Identification of components and their weights
We determined the components used in vending machines by dismantling a machine and weighing its components. Dismantling of complex components was continued until components reached a level where they consisted of one kind of material and were not complex. For simplification, some complex components such as fluorescent lights and electrical circuit boards were treated as materials here. We developed a list containing 85 component groups to which nearly 700 components belonged (**Table 1**).

Step (b): Identification of factory type
Factory types were determined for every component group including the final product. A component group and a final product might sometimes be linked to more than one factory type, as is the case with the vending machine. Although some components such as oil (as a component) were taken directly from material production, without being manufactured, a (dummy) factory type was made to avoid miscalculation (Table 1). The factory types ultimately are case independent and generally applicable. Their level of detail is a matter of further choices, based on the availability of data on the one hand, and their ease of application on the other.

Step (c): Link to factory-type database
Linking component data to these factory databases (**Table 2**), the identification of the component groups and the mass values sometimes have to be modified. For example, wood, which was used for packing the vending machine before transport, was added to the original component group. The mass of small parts, like the shoot plate, classified as from the type of factory that assembles machinery and equipment, also increased, because we included waste to be recycled and waste that was taken away from that factory. This new mass data was included as output mass from the type of factory that manufactures small metal products.

For added component groups, a procedure according to step (a) was carried out. For example, wood was linked to the factory type of 'directly coming from material production' (Table 3).

We then had a list of 89 component groups together with their final modified mass data (**Table 4**). The mass data were multiplied by input/output coefficients from Table 2 to determine the total environmental burden generated in the manufacturing stage.

Table 1: Identifying factory type (partial results for demonstration)

Component Groups/ Final Products of Vending Machine	Dismantling Level* [Code]**	Factory Type
Vending Machine	Level1 [1]	Packing up heavy machinery and equipment Painting Assembly of machinery and equipment
Small Part, like shoot plate	Level 2 [1.1]	Manufacture of small metal products
Cabinet	Level 2 [1.2]	Manufacture of fabricated metal plate products
Bolt	Level 2 [1.3]	Manufacture of small metal products
Cover	Level 2 [1.4]	Manufacture of plastic products
Tray	Level 2 [1.5]	Manufacture of plastic products
Gasket	Level 2 [1.6]	Manufacture of plastic products
Compressor	Level 2 [1.7]	Assembly of machinery and equipment
Cabinet	Level 3 [1.7.1]	Manufacture of fabricated metal plate products
Rotor	Level 3 [1.7.2]	Manufacture of small metal products
Sharft	Level 3 [1.7.3]	Manufacture of small metal products
Vane	Level 3 [1.7.4]	Manufacture of small metal products
Spring	Level 3 [1.7.5]	Manufacture of small metal products
Oil Pipe	Level 3 [1.7.6]	Manufacture of small metal products
Electrode	Level 3 [1.7.7]	Manufacture of small metal products
Succession Tube	Level 3 [1.7.8]	Manufacture of small metal products
Oil (as a component)	Level 3 [1.7.9]	Directly coming from materials
CFC-12 (as a component)	Level 3 [1.7.10]	Directly coming from materials
Electricity Distribution	Level 2 [1.8]	Manufacture of electricity distribution and control apparatus
Cord	Level 3 [1.8.1]	Manufacture of plastic products
Copper Wire	Level 4 [1.8.1.1]	Directly coming from materials
Cover	Level 4 [1.8.1.2]	Directly coming from materials
Lamp	Level 2 [1.9]	Directly coming from materials

* Level 1: final product
Level 2: products of which the final product is composed
Level 3: products of which the level 2 product is composed
Level 4: products of which the level 3 product is composed
** Component order: indication to which product the product belongs

Table 2: Factory type database

Factory Type	Input Mass kg/kg	Paint kg/kg	Wood kg/kg	Nail kg/kg	PS kg/kg	Recyclable Waste kg/kg	Waste kg/kg	Water Consumption kg/kg	CO2 kg-C/kg	Energy* Mcal/kg
Assembly of machinery and equipment	1.0003	0	0	0	0	0.00	0.0003	2.2	0.010	0.20
Directly coming from materials	1.0000	0	0	0	0	0.00	0.0000	0.0	0.000	0.00
Manufacture of electricity distribution and control apparatus	1.0013	0	0	0	0	0.00	0.0013	1.0	0.029	0.61
Manufacture of fabricated metal plate products	1.1878	0	0	0	0	0.18	0.0053	5.2	0.041	0.84
Manufacture of plastic products	1.0007	0	0	0	0	0.00	0.0000	4.5	0.002	0.02
Manufacture of small metal products	2.0151	0	0	0	0	1.01	0.0038	6.9	0.041	0.78
Painting	1.0000	7.101E-06	0	0	0	0.00	0.0000	1.0	0.055	0.96
Packing up heavy machinery and equipment	1.0000	0	0.094	0.0032	0.0003	0.00	0.0045	0.0	0.000	0.01
Transportation of heavy machinery and equipment for 100km	1.0000	0	0	0	0	0.00	0.0973	0.0	0.001	0.02
Transportation of materials to factory for 100km	1.0000	0	0	0	0	0.00	0.0000	0.0	0.001	0.02

* Energy content of fuel and primary energy of electricity: consideration of energy source which could be depleted

Table 3: Identifying factory type for modified components (partial results for demonstration)

Component Group	Factory Type
Wood	Directly coming from materials
Nail	Manufacture of small metal products
PS	Manufacture of plastic products
Paint	Directly coming from materials

2.3 Contribution of CMA to assessment of material production

Although the assessment of material production is not a part of CMA, CMA is linked to the material production stage. The factory type input-output coefficients are not only used for estimating the environmental burdens, but also provide an estimation of the required materials (Table 4).

Table 4: Final modified results and material mass (partial results for demonstration)

Final Modified Component Group/ Final Product	Dismantling Level* [code]**	Material	Final Modified Mass kg	Raw Material kg
Vending Machine (for transportation)	Level 1 [1]	Complex	318.714	
Wood(as a component)	Level 2 [1.10]	Wood (as a material)	29.879	29.879
Nail	Level 2 [1.11]	Wire Steel	1.020	2.055
PS	Level 2 [1.12]	PS	0.110	0.110
Vending Machine (for painting)	Level 1 [1]	Compex	318.714	
Paint	Level 2 [1.13]	Paint	0.003	0.003
Vending Machine (for assembly)	Level 1 [1]	Complex	318.714	
Small Part, like shoot plate	Level 2 [1.1]	SGCC	138.811	279.717
Cabinet	Level 2 [1.2]	Paint Steel	114.032	135.445
Bolt	Level 2 [1.3]	Wire Steel	0.497	1.002
Cover	Level 2 [1.4]	PE	0.205	0.205
Tray	Level 2 [1.5]	PP	1.338	1.339
Gasket	Level 2 [1.6]	PVC	3.062	3.064
Compressor	Level 2 [1.7]	Complex	9.503	
Cabinet	Level 3 [1.7.1]	SPHC	2.196	2.609
Rotor	Level 3 [1.7.2]	Section Steel	3.226	6.501
Shaft	Level 3 [1.7.3]	Cast Iron	1.594	3.212
Vane	Level 3 [1.7.4]	Section Steel	0.011	0.022
Spring	Level 3 [1.7.5]	Wire Steel	0.003	0.006
Oil Pipe	Level 3 [1.7.6]	Section Steel	0.017	0.034
Electrode	Level 3 [1.7.7]	Wire Steel	0.015	0.030
Succession Tube	Level 3 [1.7.8]	Copper	0.020	0.040
Oil (as a component)	Level 3 [1.7.9]	Oil (as a material)	2.143	2.143
CFC-12 (as a component)	Level 3 [1.7.10]	CFC-12 (as a material)	0.280	0.280
Electricity Distribution	Level 2 [1.8]	Complex	4.498	
Cord	Level 3 [1.8.1]	Complex	4.504	
Copper Wire	Level 4 [1.8.1.1]	Copper	3.606	3.606
Cover	Level 4 [1.8.1.2]	PVC	0.901	0.901
Lamp	Level 2 [1.9]	Fluorescent Light	0.023	0.023

* Level 1: final product
Level 2: products of which the final product is composed
Level 3: products of which the level 2 product is composed
Level 4: products of which the level 3 product is composed
**Component order: indication to which product the product belongs

CMA provides only mass data on the materials needed in manufacturing. Further assessment of the material production stage is not a part of CMA. For making an example, however, we performed a simplified assessment of the material production stage using practically available data. From the material production data for steel, plastics and other materials found in existing applications of LCA (Otoma et al. 1998), we derived the energy consumption intensities and CO_2 emission intensities for the material production, taking into consideration the assumptions of that research. For other input-output intensities, such as of waste and water consumption, we used values from existing LCA software (Pre Consultants 1997). The values obtained (Table 5) were then multiplied by the material masses.

2.4 Establishing factory types and completing the database

The factory classification only partly corresponded to the current sectoral classification of industries (Table 6). Thus, the factory type ranging for assembly of machinery and equipment corresponded with a range of sectoral classes from engines, class number 29.11 in NACE (European Union 1999) classification, to brushes, number 36.6. However, class 28.7 for the manufacture of small metal products was divided into two categories, and we combined one category with class 28.6; that is, we had to restructure the sectoral classification. In addition, some factory types such as painting are not treated in sectoral classification and some, such as transport of heavy machinery and equipment, are not distinguished and are mixed in one sectoral class.

In order to calculate the coefficients for the factory-type database, we obtained the agreement of subcontractors (for component factories) and final manufacturers (for product assembly) to collect input and output data of representative processes. Averages of these data were taken and compiled for each factory type.

Table 5: Intensity of input and output in the material production stage

Materials	Waste kg/kg	Water Consumption kg/kg	CO_2 kg-C/kg	Energy* Mcal/kg
SPHC	0.399		0.421	5.44
SPCC	0.399		0.479	5.936
SGCC	0.395		0.523	6.473
SECC	0.395		0.516	6.279
Paint Steel	0.399		0.559	6.719
Wire Steel	0.399		0.671	5.447
Stainless Steel	0.399		1.311	12.309
Section Steel	0.399		0.357	5.399
Cast Iron			0.661	7.948
Aluminium	0.219		2.848	37.484
Copper			0.913	8.422
Zinc	0.600		1.124	9.105
PE	0.034	18.0	0.247	15.599
PP	0.031	3.1	0.281	15.565
PVC	0.130	1.9	0.372	11.100
ABS			0.629	20.123
PMMA			0.581	19.063
PA			0.809	19.784
PC	0.107		1.386	29.621
POM			1.085	23.657
PET	0.042		0.823	19.867
PUR	0.020	0	0.669	18.369
PS	0.025	9.8	0.822	23.614
PF			0.617	15.587
Oil			0.878	10.909
CFC-12			2.425	19.744
Glass Fiber			0.579	7.967
Electric Component			7.375	61.380
Fluorescent Light			0.819	10.007
Wood	0.265		0.069	2.941
Paint			0.553	10.650

*Energy content of fuel and primary energy of electricity: consideration of energy source which could be depleted

The coefficients were restricted to some inputs and outputs, because enough data could not be collected for others at this time. The factory-type database should be developed to cover whole inputs and outputs for simplification of the full LCA. As an option, the coefficients of screening indicators such as MIPS (Christiansen et al. 1997) can be calculated and added on the factory-type database. The goal of CMA is, however, to make a desirable LCI method for the manufacturing stage and not to support the screening methods.

Table 6: Relation between factory types and sectoral classification

Factory Type	NACE classification	JAPAN classification
Assembly of machinery and equipment	29-36	3011-3919
Directly coming from materials	Not Existing	Not Existing
Manufacture of electricity distribution and control apparatus	31.2	3421.041
Manufacture of fabricated metal plate products	28.71-72, 75	2899.091
Manufacture of plastic products	25.2	2211.01
Manufacture of small metal products	28.6, 28.73-74	2899.011, 031, 033, 092, 099
Painting	Not Existing	Not Existing
Packing up heavy machinery and equipment	Not Existing	Not Existing
Transport of heavy machinery and equipment for 100km	60.24	7121.011
Transport of materials to factory for 100km per kg	60.24	7121.011

2.5 LCI results

Fig. 3 presents the LCI of the various stages: material production, manufacturing, utilization, and waste management. Nearly half of the final waste occurred in the waste management stage of the product discarded after use, as we assumed that no recycling takes place. The Manufacturing stage shared one third of the whole waste. The material production stage had the least share. Water was almost all consumed in the manufacturing stage. Because the vending machine has a long lifetime, its energy consumption and CO_2 emissions during use accounted for a large proportion of the totals. Thus, as a whole, the manufacturing contributed significantly to many kinds of the environmental inputs and outputs, compared to the other stages.

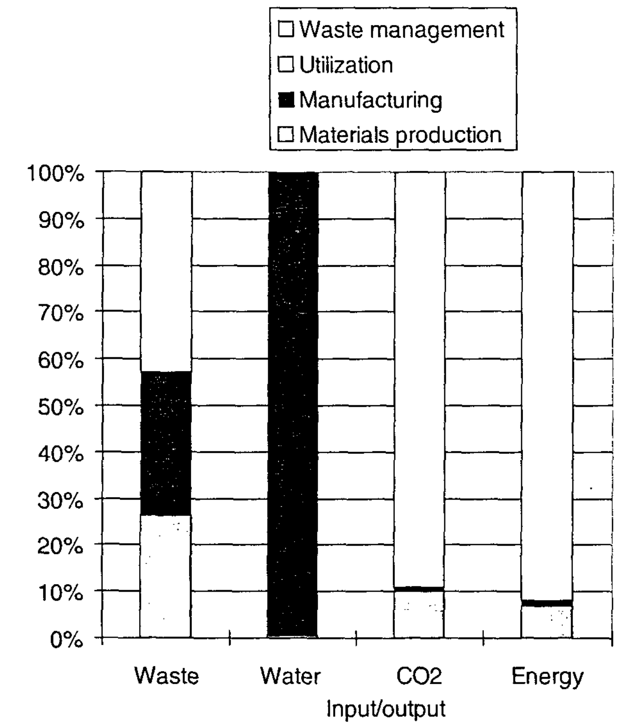

Fig. 3: LCI results

This result revealed that the assumption that the manufacturing stage may be ignored, as in screening approaches, may lead to a faulty LCI analysis, with a significant possibility of leading to a wrong decision. Although it can depend on a product whether the screening leads to a fatal wrong result or not, the LCI analysis should deal with the whole life stages to avoid a danger of faulty understanding.

In addition, CMA provides the required material masses which include a part not going into the product, i.e. waste generated in the manufacturing stage. If LCI analysis excludes the manufacturing stage and ignores the waste generated in the manufacturing stage, the required material masses are estimated lower than true values. **Fig. 4** shows the contribution of manufacturing including inputs and outputs related to the material production which eventually become waste. In our case study, all inputs and outputs related to manufacturing were much larger than those directly contributing to the manufacturing stage (see, Fig. 3 and 4). The contribution of the manufacturing stage was about five percent for the energy consumption and related CO_2 emissions. Although this value was still not big, if a difference from an alternative product at other stages was small, the inputs and outputs related to manufacturing might possibly change a decision. For the waste and water, manufacturing and related processes contributed significantly to the environmental inputs and outputs.

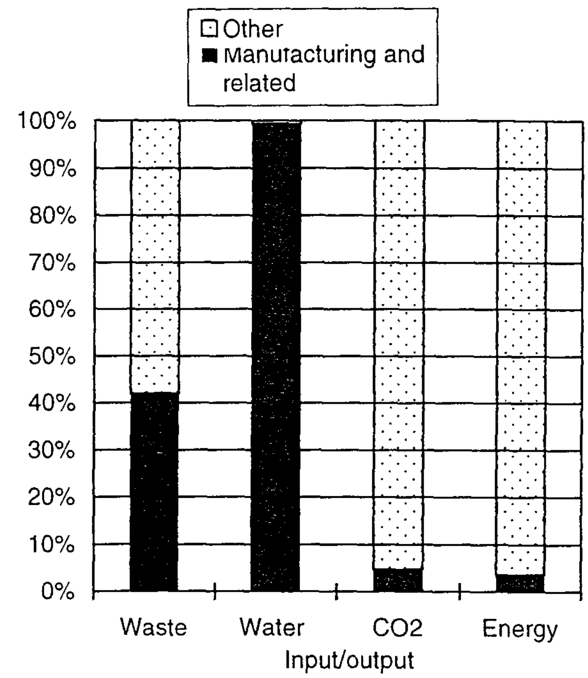

Fig. 4: The importance of manufacturing stage

Thus LCI analysis that excludes the manufacturing stage may lead to significant underestimates in LCI, and consequently to misunderstanding and misjudgment in interpretation.

3 Evaluation of CMA

Specifying components and identifying their mass were easy procedures. The requirement to obtain values for CMA was simply to break down the product into components and put them on a scale. A point of attention was how to determine the level at which component disassembly should be stopped. Lists of materials according to the material production database would be helpful in specifying the level for stopping, because materials do not have to be disassembled any more.

Another attention point was double counting. For example, when a product consists of a steel door, and of course other components not further treated here, and the door consists of several steel plates, it should be determined whether both the door and the steel plates are considered as two levels in decomposition, or only the steel plates are considered and not the door as a separate step. In the two step procedure, the mass of steel plates included in the door is applied in the calculation twice. This is the problem of how to define components. Subjective judgment on definition of components has to be avoided. The criterion used here is the actual production process. In this case study, there was a one step proce-

dure, because the door was not an independent product made at a specific factory. When in doubt, one principle might be that a component should be a sold product which is on the market. This principle could reduce difficulties to define components. However, more specific requirements should be prepared, especially in situations where there is a large degree of vertical integration in the component production concerned.

Identifying factory types for the different components was not a difficult procedure. However, a manual that describes the components to be linked to each factory type would make it easier to perform this step.

Since the factory database is generic and calculation was done automatically, linkage of components to the factory-type database required no arbitrary procedure. In addition, it was not necessary to investigate a full process tree for obtaining the input and output data. So, after setting up the factory types and filling the database, the resulting procedure at the case level was quite simple.

One of the difficulties in establishing a factory-type database concerns the assurance of accuracy. If a factory develops a really new technology and uses it only to manufacture one specific (group of) component(s), a new factory type could be made for that factory. The more detailed the established factory types are, the more accurate will be the results, but the greater will be the effort needed for gathering data. Also, more specific knowledge is needed for its application. The factory types applied to this case study were established without considering a specific new technology in a specific factory. If a CMA user complains about the values used in the factory-type database, one solution is to allow use of specific process data explicitly showing where the data have been changed.

Another difficulty is the confidentiality of factory data. Although input and output data are primarily the property of the factories, nowadays many enterprises have become environmentally conscious and have a tendency to release data to the public. We were able to obtain the cooperation of a number of factories in collecting data on input and output amounts. The key point was to find companies that wanted a proper LCI result.

A factory-type database can include overhead input-output such as lighting and heating a room. Exclusion of them is also possible. This is a matter of choice of method and data sources. In this study, the overhead input-output was included in the calculation, as this gives the fullest picture of environmental effects.

4 Conclusion

CMA results for the beverage vending machine showed that the manufacturing stage significantly contributed in analyzing the whole life cycle of a product from the viewpoint of its environmental relevance. LCI excluding the manufacturing stage could often result in an incorrect LCA. Hence, the manufacturing stage should not be omitted in LCA.

CMA needs the flow of components through certain factory types instead of process trees. Therefore, CMA differs from other available LCI tools based on the processes. CMA is aiming to encompass all of the environmental input and output not to use screening indicators. CMA is a quite new simplified method which has no screening procedure.

CMA appears to be an easy, reliable and consistent, non-arbitrary method for LCI of the manufacturing stage of a product life cycle, as the case of the vending machine has shown. Standardized manuals, including generic factory type databases, can make the application of CMA still easier. In principle, CMA calculations can then be carried out automatically. Such CMA leaves little room for subjectivity and can encompass all inputs and outputs of the whole manufacturing stage. Although the result of CMA could not be compared with an unsimplified LCI result, because there was no such a full result, the standardized manuals will also determine the accuracy of CMA results.

Further development of the CMA method, specifying a generic set of factory types and building a generic data set, seems well worth an investment, because more reliable and less costly LCAs can then be made.

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